Technical Memorandum No. 33-162

Oblique Shock Wave Angle Charts for a Perfect Gas (γ = 1.20, 1.26, 1.40, and 1.67)

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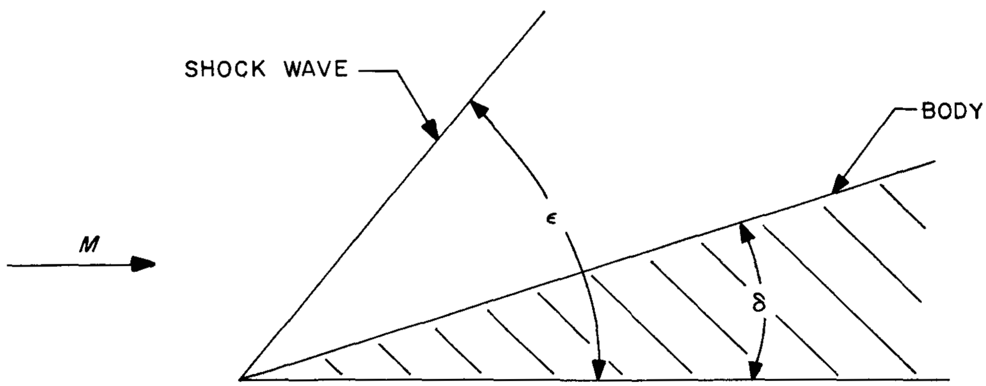
When operating in the perfect gas regime of planetary atmospheric gases in conventional wind tunnels, and in solving two-dimensional flow problems, the aerodynamicist requires charts illustrating the variation of oblique shock-wave angle with turning angle. For this purpose, the oblique shock-wave angle as a function of turning angle has been computed for Mach numbers to 10 in accordance with the shock theory. Specific heat ratios of 1.20, 1.26, 1.40, and 1.67 were used.

Using the proper trigonometric relations, these charts may be used in conjunction with normal shock tables to obtain the thermodynamic characteristics of a perfect gas behind an oblique shock wave.

I. INTRODUCTION

In the continuum regime of gasdynamic flow, a shock wave is formed ahead of a body exposed to a supersonic gas stream, as shown in the following sketch. For the turning angle or body angle (δ) sufficiently small, the shock wave will be attached to the body. The angle (ϵ) of a shock attached to a two-dimensional body may be obtained from the enclosed charts. The shock-wave angle (ϵ) is required by the aerodynamicist in order to relate the thermodynamic conditions behind the shock to those in the freestream ahead of the shock.



II. DESCRIPTION OF CHARTS

The relationship between the Mach number (M), ratio of specific heats (γ), and turning (δ) determining the two-dimensional shock-wave angle was computed from shock theory (Ref. 1)

$$\frac{1}{\tan\,\delta} = \left[\frac{\gamma+1}{2}\,\frac{M^2}{M^2\sin^2\epsilon - 1} - 1\right]\tan\,\epsilon$$

The angle for shock detachment (ϵ_m) was then computed as follows

$$\sin^2\epsilon_m = \frac{1}{\gamma M^2}\left\{\frac{\gamma+1}{4}\,M^2 - 1 + \left[\frac{\gamma-1}{2}\left(M^2 + \frac{\gamma+1}{16}\,M^4\right)^{1/2}\right]\right\}$$

The variation of turning angle (δ) with shock-wave angle (ϵ) is illustrated in Figs. 1 through 4 for ratios of specific heats (γ) of 1.2, 1.26, 1.40 and 1.67, respectively. On these charts, Mach number (M) is a parameter, with Mach numbers from 1.2 to 10.0 being illustrated.

These same values of the variables are cross-plotted in Figs. 5 through 8, with the variation of shock-wave angle with Mach number being illustrated. The turning angle with values from 0 to 50 deg has been plotted as a parameter in these curves.

In order to illustrate the effect of the ratio of specific heats on the shock-wave angle, the variation of shock-wave angle with the ratio of specific heats has been cross-plotted in Fig. 9 for a Mach number of 5.0, and for several values of the turning angle. It may be seen that the shock tends to steepen as the ratio of specific heats increases for all finite values of turning angle.

III. USE OF CHARTS

The charts may be used in computing the thermodynamic quantities, density, temperature, Mach number, and pressure behind an oblique shock on a two-dimensional body where these curves are applicable; i. e., low enthalpy, attached shock, etc. The ratios of the thermodynamic quantities across the shock may be obtained from the normal shock relationships found in gas-flow tables (Ref. 2) simply by reading the tabulated values at the Mach number normal to the shock (M_1), rather than the freestream Mach number (M); that is

$$M_1 = M \sin \epsilon$$

The Mach number behind the oblique shock (M_2') may be obtained by adding vectorially the Mach number parallel to the shock ($M \cos \epsilon$) and the Mach number (M_2) behind the normal shock wave. M_2 is found in the table at M_1.

Solving the geometry, the magnitude of the Mach number is

$$M_2' = (M^2 \cos^2 \epsilon + M_2^2)^{1/2}$$

and the direction, of course, is parallel to the body at angle δ from the freestream.

ACKNOWLEDGEMENT

The author is grateful to Mrs. Carolyn Wise and Miss Carolyn Adolphe for their effort and patience in computation and plotting.

NOMENCLATURE

M	mach number ahead of oblique shock
γ	ratio of specific heats
δ	stream-turning angle (deg from freestream direction)
ϵ	shock-wave angle (deg from freestream direction)

REFERENCES

1. Ferri, A., *Elements of Aerodynamics of Supersonic Flows,* The MacMillan Co., New York, 1949.

2. Wang, C. J., et. al., *Gas Flow Tables,* GM-TR-154, Space Technology Laboratories, Inc., Los Angeles, California, 14 March 1957.

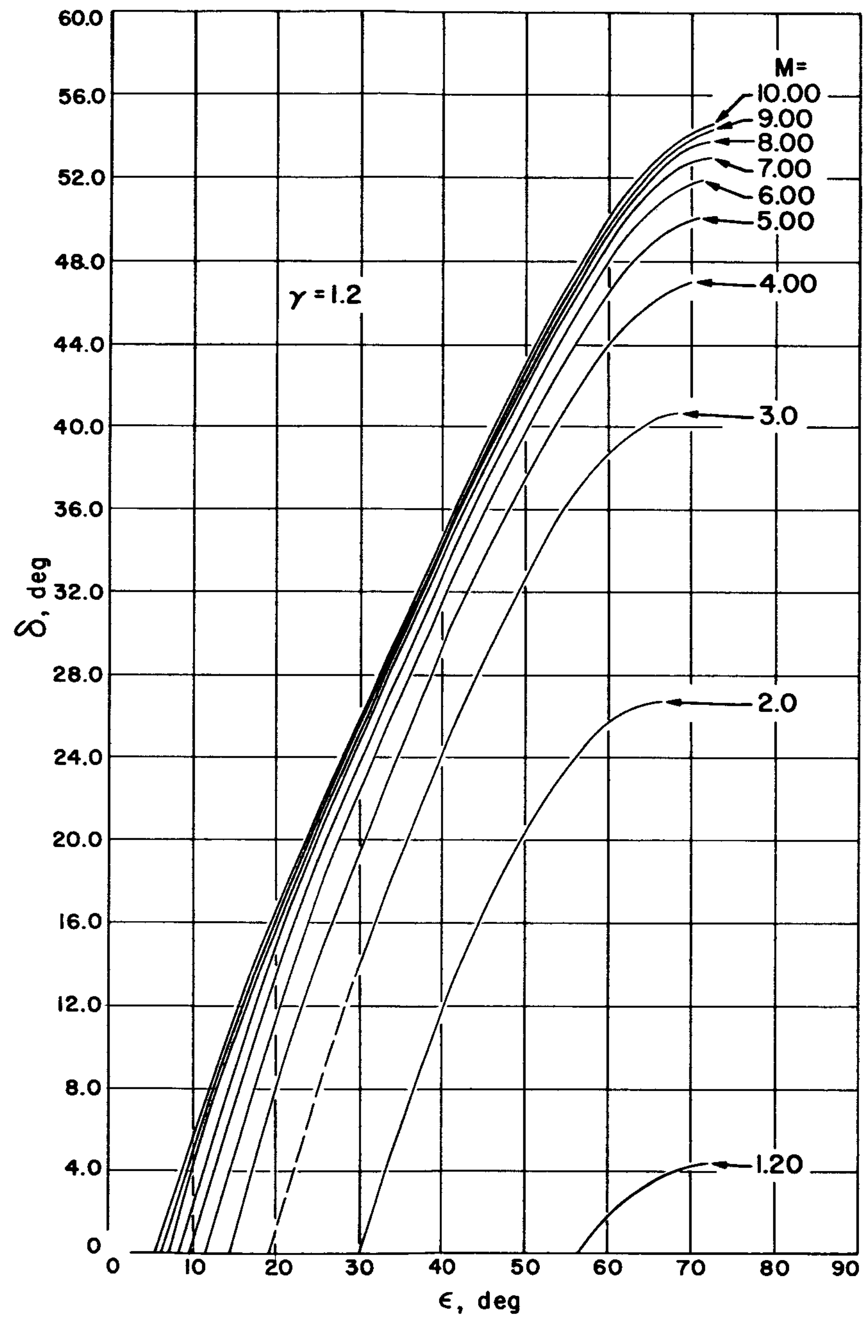


Fig. 1. Variation of turning angle with shock-wave angle (γ = 1.20)

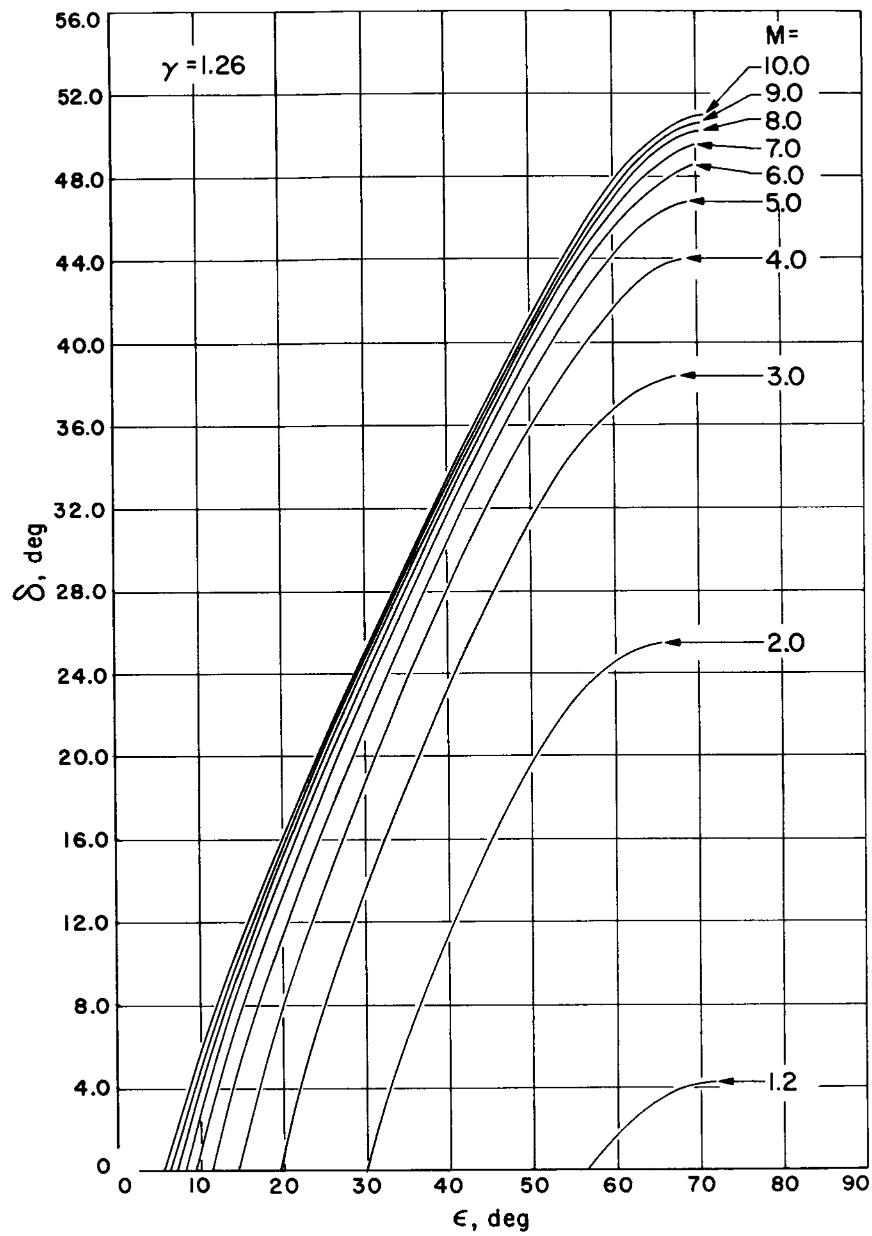


Fig. 2. Variation of turning angle with shock-wave angle (γ = 1.26)

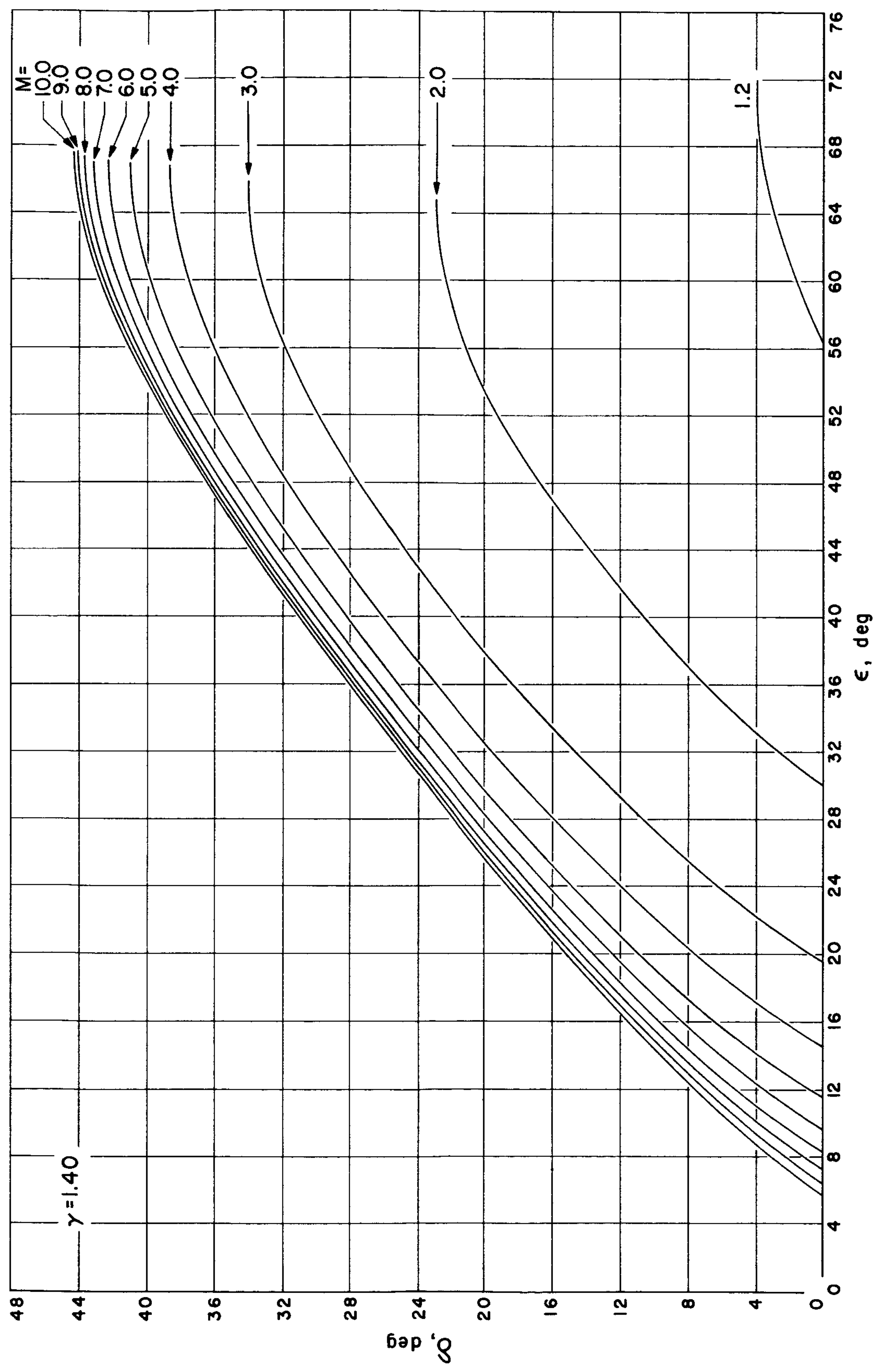


Fig. 3. Variation of turning angle with shock-wave angle (γ = 1.40)

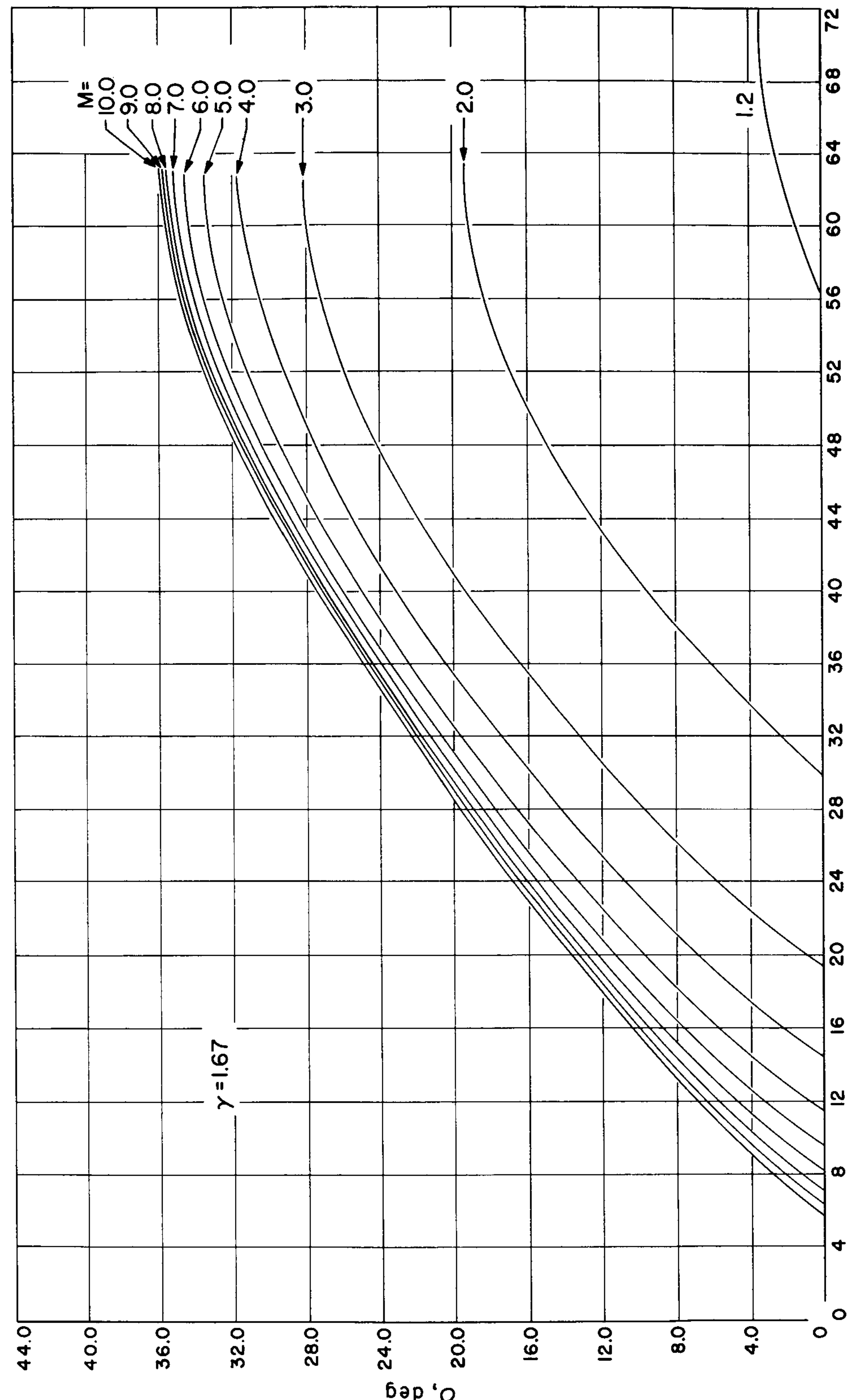


Fig. 4. Variation of turning angle with shock-wave angle ($\gamma = 1.67$)

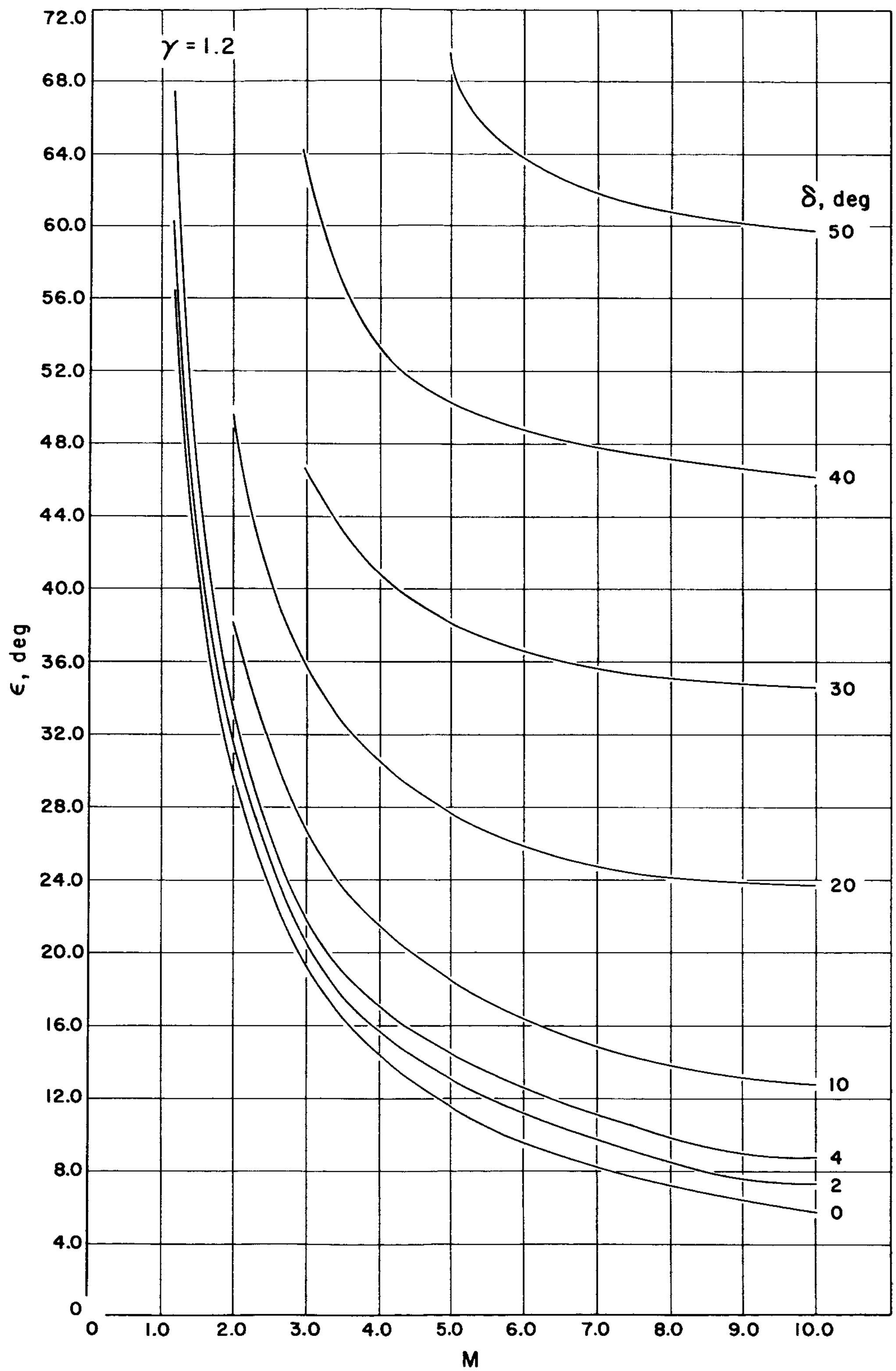


Fig. 5. Variation of shock-wave angle with Mach number ($\gamma = 1.20$)

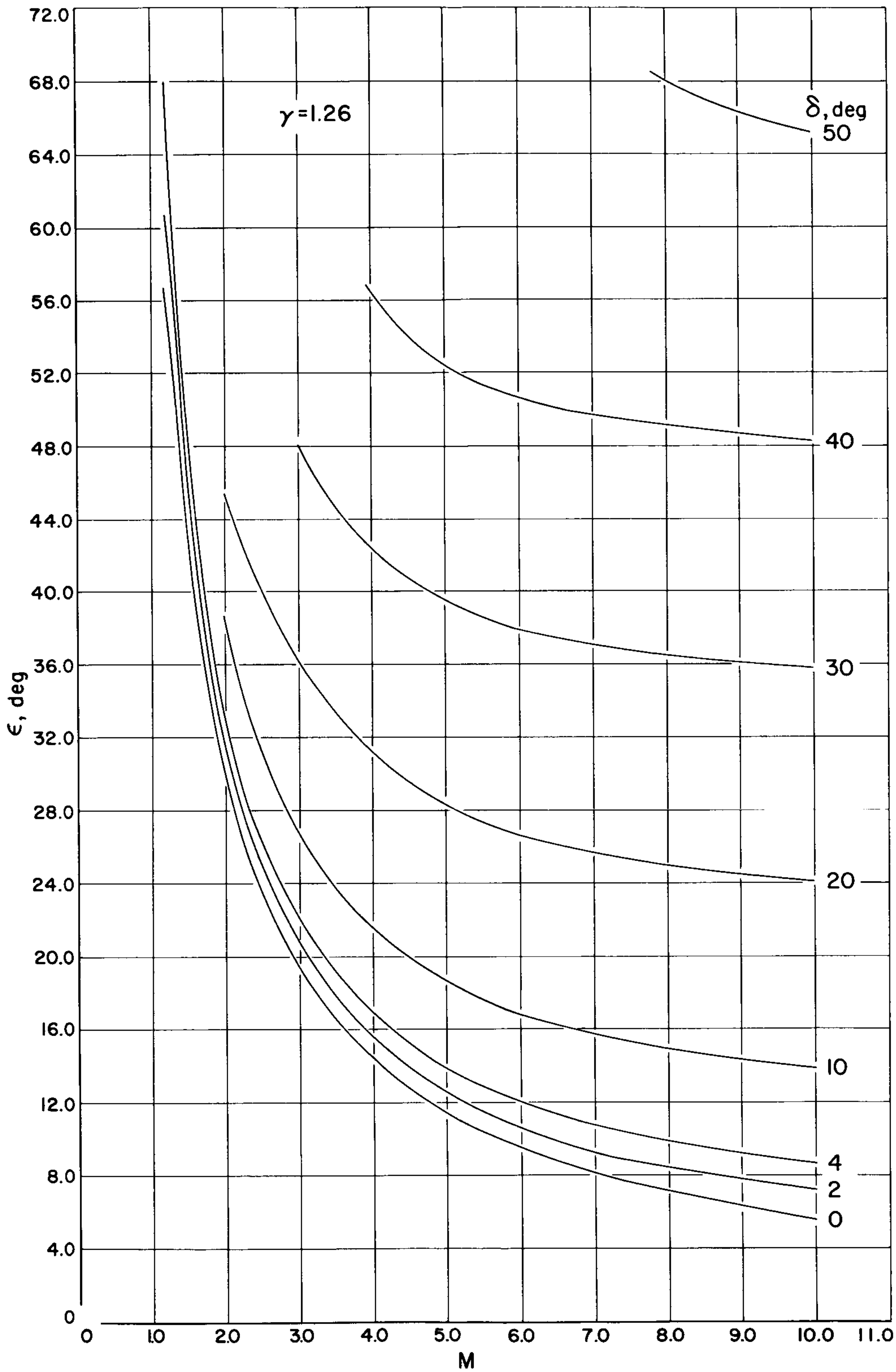


Fig. 6. Variation of shock-wave angle with Mach number (γ = 1.26)

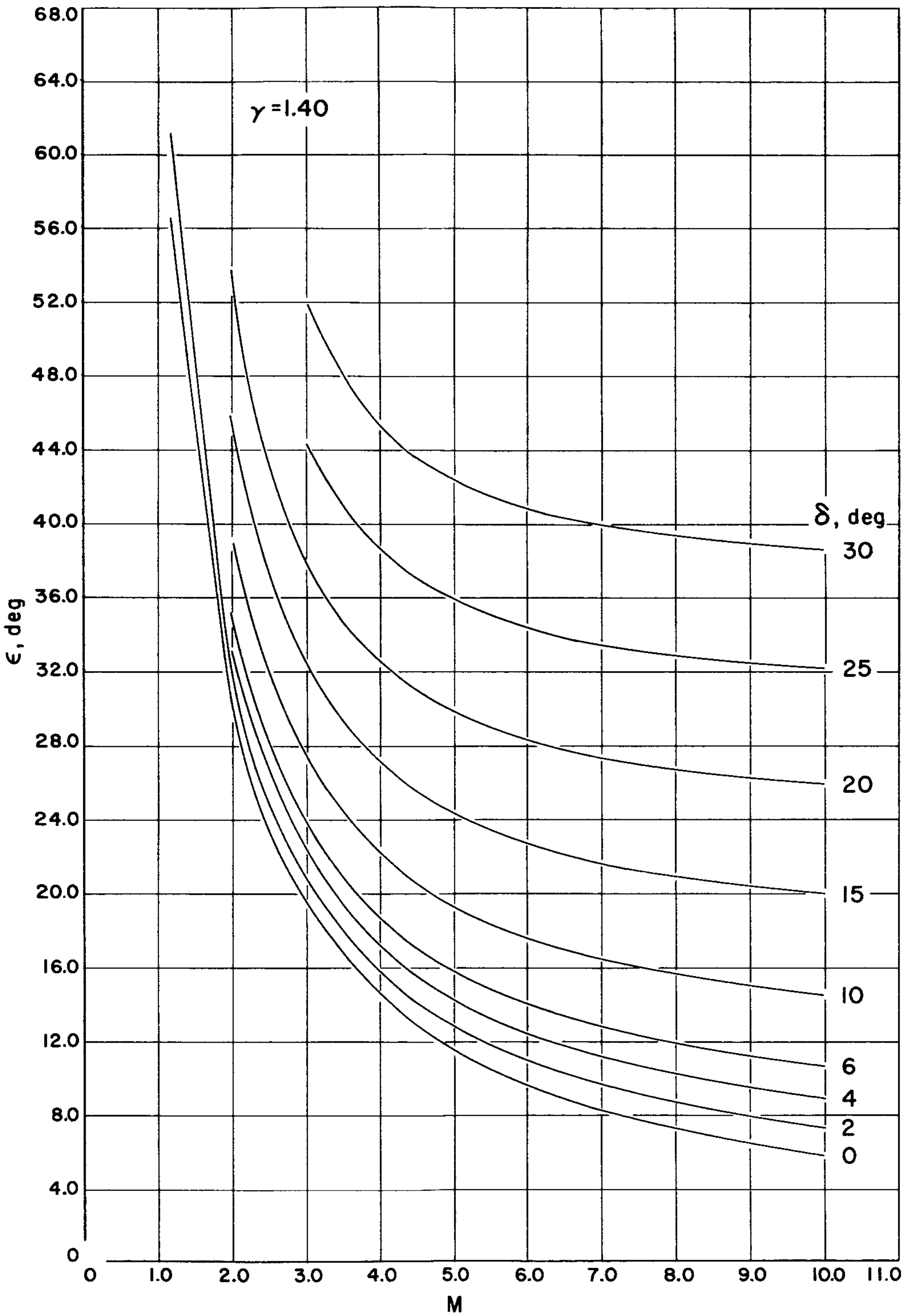


Fig. 7. Variation of shock-wave angle with Mach number (γ = 1.40)

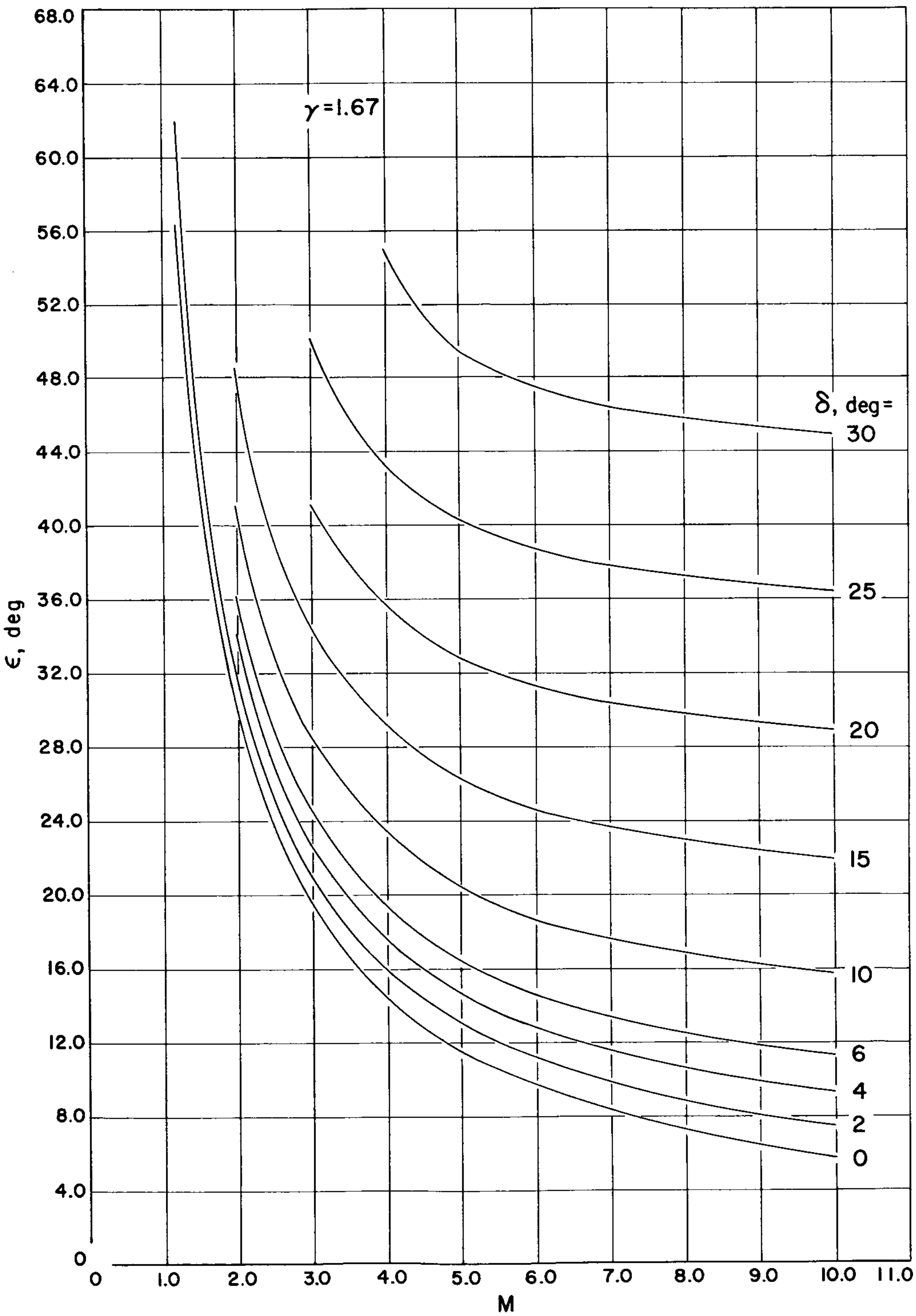


Fig. 8. Variation of shock-wave angle with Mach number (γ = 1.67)

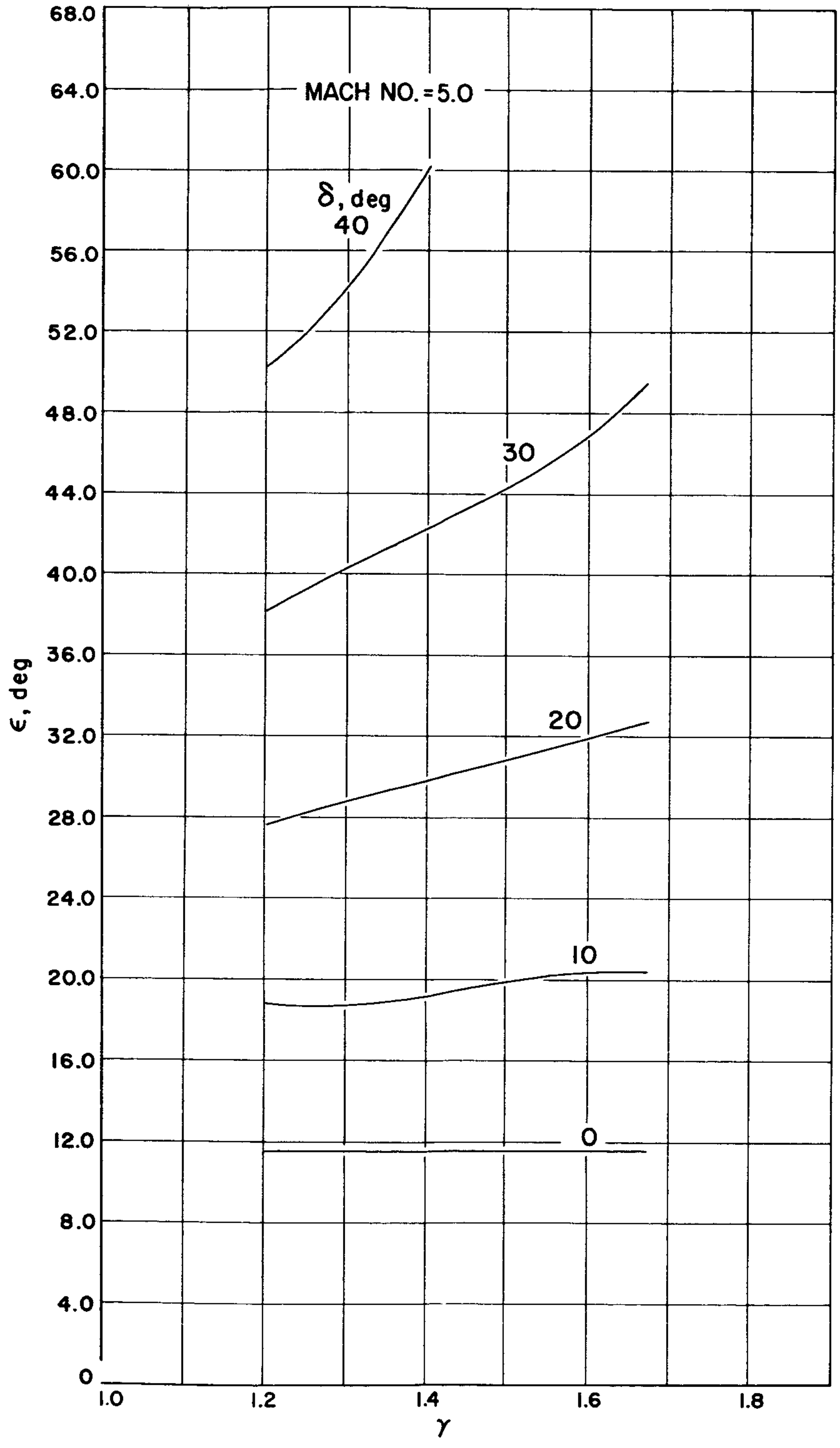


Fig. 9. Variation of shock angle with the ratio of specific heats